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Planetary® production type MOCVD reactors for blue laser applications in the GaInN material system

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Abstract. Growth parameters for the growth of heterostructures in the GaN/GaInN material system are studied through numerical simulation of thermal, fluid dynamical and kinetical behavior of the AIX 2000 G3 HT Planetary® reactor. Good on wafer, wafer to wafer and run to run uniformity over the whole spectral range are demonstrated. Lasing at wavelengths up to 470 nm of such structures is achieved by optical pumping at 300 K, proving high optical quality of the obtained layers and good control of the formation of quantum dot or disk like organization of In-rich clusters in the QW material.

Introduction

By now heterostructures in the material system GaInN/GaN are widely used for display and lighting applications in the green to blue/UV spectral range. Furthermore, nitride based lasers operating at 390 to 420 nm emission wavelength have become availabe recently [1]. GaInN-based LDs visible in the blue-violet (near 450 nm) have also been reported in the last year [2]. The metal organic vapor phase epitaxy (MOVPE) has established itself as the layer growth method of choice for these (and other) semiconductor materials. AIXTRON's AIX 2000 G3 HT system family was developed to meet the needs of modern production facilities by low overall running costs and low cost of ownership while maintaining high standards for layer quality and uniformity on wafer and wafer to wafer.

1. Experimental and results

Growth runs were performed in an AIX 2000 G3 HT reactor in the 6×2" configuration using triethylgallium (TEGa), trimethylgallium (TMGa), trimethylindium (TMIn), ammonia (NH_3), silane (SiH_4) and biscyclopentadienylmagnesium (CP_2Mg) as precursors and H_2 and N_2 as carrier gases. Structures were grown on c-plane sapphire using a conventional low temperature GaN nucleation layer with subsequent anneal step prior to a high temperature buffer layer. The active region contained 5 and 10 period MQW structures with QW thicknesses in the range of 2 to 3 nm.

To optimize on wafer deposition uniformity and to establish easily reproducible deposition processes critical steps in the growth procedure are analyzed through numerical simulation of heat transfer and fluid field interaction including species diffusion and a simplified reaction chain model. In figure 1 the conditions for the growth of GaInN at 200 mbar and 800 °C are examined. A homogenous depletion of both NH_3 and TEGa have

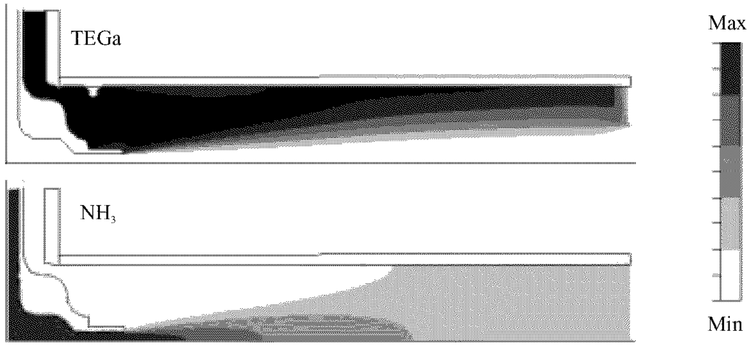

Fig. 1. Concentration profiles of TEGa (upper) and NH_3 (lower) mass flows inside the reactor chamber for $T_D = 800\,^{\circ}C$, $P_{tot} = 200$ mbar and $Q_{tot} = 28$ slm from numerical simulations – symmetry axis of the reactor chamber and the inlet are on the left hand side, direction of gas flow is left to right.

been achieved at these conditions, guaranteeing good on wafer layer uniformity through gas foil rotation of the substrates.

Figure 2 combines wafer to wafer comparison data for several runs. On the left the variation of average layer thickness for a single GaN buffer layer run is displayed (thickness on radius, angular position corresponds to load position in the reactor), showing a wafer to wafer standard deviation of 0.7%. On the right the average photoluminescence (PL) peak emission wavelength of wafers from several runs is compared in a similar way, showing 4.0 nm standard deviation at 441.5 nm, 6.7 nm at 470.7 nm, 6.4 nm at 499.3 nm, 3.0 nm at 529.0 nm and 1.9 nm at 579.8 nm. The PL spectra were recorded at $T = 300$ K under low intensity cw excitation. Clearly, material around the center of the GaInN miscibility gap (emitting at 470 to 500 nm) is most sensitive to the process conditions and thus exhibits the largest spread. Nevertheless these results evidence good control of process conditions between wafers as well as on wafer (as has been published earlier).

To further assess the quality of the layers thus grown PL and stimulated emission spectra were studied as a function of excitation intensity at low (4.2 K) and room temperature. Figure 3 shows both PL and PLE (photoluminescence excitation) spectra measured under

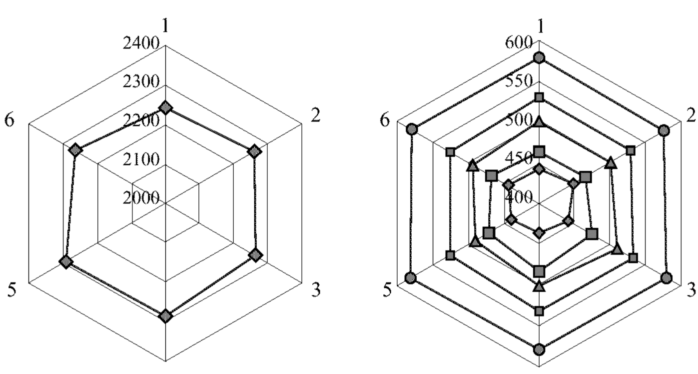

Fig. 2. Overviews for wafer to wafer reproducibility for total thickness (left) and peak emission wavelength (right) at various process conditions – the azimuthal position indicates the load position of the wafer.

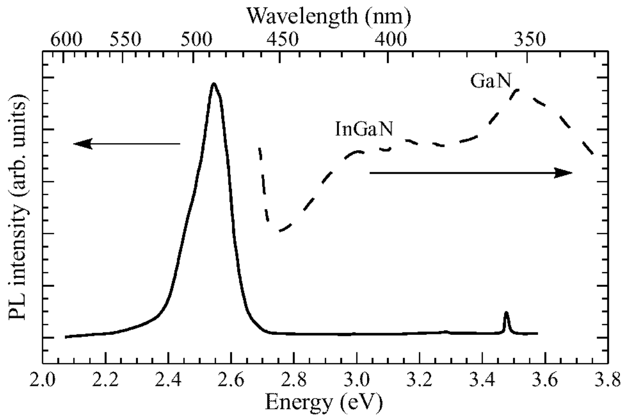

Fig. 3. Normalized PL (solid) and PLE (dashed) spectra of GaN/GaInN quantum well structures at $T = 4.2$ K.

illumination of quasi-monochromatic light dispersed from a xenon lamp by a monochromator. The PL spectrum consists of a line of low intensity near 3.5 eV, belonging to emission from the GaN barrier layers, and an intensive band from the active layers located at roughly 2.5 eV. The PLE spectrum reveals a UV band due to the light absorption in the GaN barrier and a low energy band near the mobility edge of the active layer. The high Stokes shift between the PL and PLE response of the QWs indicates that the radiative recombination at low excitation density is due to In-rich clusters inside the QW layers such as quantum dots or discs. A high efficiency in direct excitation of carriers near the mobility edge of the GaInN evidences a good quality of the active layer.

Photoluminescence and laser spectra were also taken at higher excitation densities afforded by pulsed nitrogen laser irradiation at low (78 K) and room temperature ($h\nu =$ 3.68 eV, $f = 1000$ Hz, $t = 8$ ns, $I_{ex} = [0.01, 1]$ MW cm^{-2}). Figure 4 illustrates the influence of increasing I_{ex} on the PL response of the sample examined above: a shoulder is formed on the higher energy side of the peak with increasing I_{ex}, evidencing a small extension of the emission band there, modulated by the thickness interference pattern in the buffer layer. Stimulated emission bands appear at relatively low excitation, but lasing requires higher intensities than other samples studied in comparison [3, 4] due to a reduced layer thickness and thus lower optical confinement factor in the samples studied here.

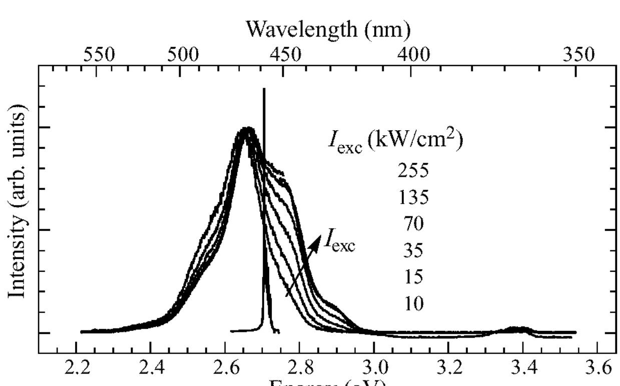

Fig. 4. Room temperature PL spectra at different excitation densities and laser spectrum (narrow).

Generally, the optical characteristics demonstrated prove excellent material quality.

2. Summary and conclusion

Investigation of growth parameters through numerical simulation of thermal, fluid dynamical and kinetical behavior of the AIX 2000 G3 HT Planetary® and experimental optimization led to good on wafer, wafer to wafer and run to run uniformity over the whole spectral range accessible via the material system GaInN. Lasing was achieved at wavelengths up to 470 nm by optical pumping at room temperature, proving high optical quality of the obtained layers and good control of the formation of quantum dot or disk like organization of In-rich clusters in the QW material. We conclude that the AIX 2000 G3 HT MOCVD system is an excellent tool for the mass production of laser structures.

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